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NUTRITION IN ULTRA-ENDURANCE RACING – ASPECTS OF ENERGY BALANCE, FLUID BALANCE AND EXERCISE-ASSOCIATED HYPONATREMIA

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Abstract

Ultra-endurance athletes try to extend their limits in performance. In ultra-endurance races, athletes face limits in nutrition regarding both energy intake and fluid metabolism. The purpose of this review is to focus on the decrease in body mass, aspects of energy and fluid balance, and exercise-associated hyponatremia in ultra-endurance performance. An ultra-endurance performance lasting 24 hours or longer may lead to an energy deficit of approximately 7,000 kcal per day. This energy deficit may result in a decrease of body mass, including a decrease in both fat mass and skeletal muscle mass. The energy deficit cannot be completely compensated by increasing energy intake. Adequate fluid intake is required during an ultra-endurance performance to prevent dehydration. In case of fluid overload, both exercise-associated hyponatremia and swelling of limbs may occur. Limited fluid intake of approximately 300-400 ml per hour may prevent both exercise-associated hyponatremia and swelling of limbs. In summary, in ultra-endurance performances, an energy deficit seems to be unavoidable, and athletes are at risk to develop both exercise-associated hyponatremia and limb swelling in case of fluid overload.

Keywords: *energy deficit, fluid overload, exercise-associated hyponatremia, limb swelling*

Ultra-endurance performances

An ultra-endurance performance is defined as an endurance performance lasting for six hours or more [1]. The most popular ultra-endurance disciplines are swimming, cycling, running and triathlon as the combination of these three disciplines. Table 1 summarizes well-known ultra-endurance races. When ultra-endurance athletes compete for hours, days or even weeks, they face different problems regarding nutrition such as dehydration, glycogen depletion, gastrointestinal discomfort and fluid overload, which may occur as a single problem or a combination of problems. The continuous physical stress leads to an energy deficit. Furthermore, the ultra-endurance performance may lead to dehydration due to sweating.

Literature regarding nutrition in endurance and ultra-endurance has already been reviewed for specific topics [1-8]. In these reviews, recommendations were made for nutritional practices in order to recover and prepare for daily training [1,6,7], protein intake during training [6,8], intake of fat prior to an endurance performance [3], intake of carbohydrates before performance [2,4,6,8-10], intake of carbohydrates during exercise [3,4,6,10,11], intake of carbohydrates after performance [4,6,10-12], protein intake for recovery [10], and fluid intake during performance [4-8,10,11,13,14].

However, the problems of energy deficit and fluid metabolism in ultra-endurance athletes have not been addressed. The main problems regarding energy and fluid metabolism of an ultra-endurance performance can be separated in two categories. The first aspect concerns the energy deficit with the corresponding loss in solid body masses such as fat mass and skeletal muscle mass. The second aspect concerns the deregulation of fluid metabolism with dehydration or fluid overload with an increased risk of exercise-associated hyponatremia (EAH). The aim of this review is to focus on the decrease in body mass, and the problems in energy and fluid balance ultra-endurance performance.

Nutritional problems associated with ultra-endurance performance

Energy turnover and energy deficit in ultra-endurance

Most research conducted on extreme endurance (>3 hours) is based on case studies and studies involving a small number of individuals [5]. Conducting research in these events is challenging and the number of studies is very limited. Due to the lack of research and the complexities in conducting research in ultra-endurance races, we are dependent on scientific findings from other similar endurance sports. Thus findings for nutrition in endurance performance shorter than six hours in duration are examined first. For endurance exercise lasting 30 min or more, the most likely contributors to fatigue are dehydration and carbohydrate depletion [7], whereas gastrointestinal problems, hyperthermia, and EAH can reduce endurance exercise performance and are potentially health threatening, especially in events of four hours or longer in duration [7,15]. Gastrointestinal problems occur frequently, especially in long-distance triathlons [15]. Problems seem to be related to the intake of highly concentrated carbohydrate solutions, or hyperosmotic drinks, and the intake of fibers, fat and protein [15].

Meeting macronutrient and fluid intake demands is of highest priority for ultra-endurance athletes [4]. An ultra-endurance athlete competing for hours or days with or without breaks expends considerable amounts of energy [16-37]. Meeting the energy demands of ultra-endurance athletes during racing requires careful planning and monitoring of food and fluid intake [25,38]. Adequate carbohydrate and fluid intake during an endurance performance may help to reduce fatigue and enhance performance [10]. Current evidence continues to support mandatory high carbohydrate intakes before an event to maximize muscle glycogen stores and during an event to prevent hypoglycemia [4]. Numerous case reports [17,25,28-34,39] and field studies [19,24,27,40-44] showed, however, that ultra-endurance athletes were unable to self-regulate diet or exercise intensity to prevent a negative energy balance. Estimation of energy expenditure prior to the beginning of an ultra-endurance event would allow athletes to plan the diet energy intake better [44]. Furthermore, the insufficient energy intake is associated with malnutrition such as a low antioxidant vitamin intake [45].

Adequate food and fluid intake is related to a successful finish of an ultra-endurance race [24,46,47]. An important key to a successful finish in an ultra-endurance race seems to be an appropriate nutrition strategy during the race [47]. Additionally, an energy deficit inhibits ultra-endurance performance. A significant negative relationship between energy intake and time taken to complete a 384-km cycle race is documented in ultra-cyclists [43]. An ultra-endurance performance results in an energy deficit [17,19-31,34,36-39,48-55].There are reports of energy expenditures of ~365-750 kcal/hour with total energy expenditures of ~18 000-80 000 kcal, which were required to complete adventure races. These energy expenditures were accompanied by significant negative energy balances during competitions [8].

In Table 2, results from case and field studies are summarized and separated by discipline (*i.e.* swimming, cycling, running and the combination as triathlon). Regarding the single disciplines, the energy deficit seems higher in swimming compared to cycling and running. This might be explained by the different environment (*i.e.* water) as compared to cycling and running. Alternatively, swimming may involve more skeletal muscle mass than cycling or running. Or it could be that swimmers ingest fewer calories during performance than runners or cyclists do. For events lasting 24 hours or longer, the energy deficit is highest

Table 1. *Well-known ultra-endurance races in swimming, cycling, running and triathlon*

Discipline	Distance	Website
	Swimming	
Channel Swimming	~34 km, sea water	www.dover.uk.com/channelswimming
Cycling		
Furnace Creek 508	~820 km in California, USA	www.adventurecorps.com
Tortour	~1,000 km around Switzerland	www.tortour.ch
Race around Ireland	~2,200 km around Ireland	www.racearoundireland.com
Race around Austria	~2,200 km around Austria	www.racearoundaustria.at
Race across America	~4,800 km across America	www.raceacrossamerica.org
	Running	
Ultra Trail du Mont Blanc	166 km	www.ultratrailmb.com
Badwater	217 km	www.badwater.com
Spartathlon	246 km	www.spartathlon.gr
Marathon des Sables	~240 km	www.darbaroud.com
Western States Endurance Run	161 km	www.ws100.com
Trans Europe Foot Race	~5,100 km	www.transeurope-footrace.org
	Triathlon	
Virgina Double Iron Triathlon	7.6 km swim, 360 km bike, 84.4 km run	www.usaultratri.com
Virgina Triple Iron Triathlon	11.4 km swim, 540 km bike, 126.6 km run	www.usaultratri.com
Deca Iron Triathlon Mexico	36 km swim, 1,800 km bike, 420 km run	www.multisport.com.mx

Table 2. *Energy balance in ultra-endurance athletes in different disciplines*

Distance and/or time	Subjects	Total energy intake (kcal)	Total energy expenditure (kcal)	Total energy deficit (kcal)	Energy deficit in 24 hours (kcal)	Energy deficit per hour (kcal)	Reference
Swimming							
26.6 km	1 male	2,105	5,540	- 3,435		- 429	30
26.6 km	1 male					- 500	48
24-h swim	1 male	3,900	11,460	- 7,480	- 7,480	- 311	49
Mean (SD)						- 413±95	
Cycling							
12 hours indoor-cycling	1 male	2,750	5,400	- 2,647		- 220	34
557 km in 24 hours	1 male	5,571	15,533	- 9,915	- 9,915	- 413	39
617 km in 24 hours	1 male	10,000	13,800	- 3,800	- 3,800	- 158	28
694 km in 24 hours	1 male	10,576	19,748	- 9,172	- 9,172	- 382	25
24 hours cycling	6 males	8,450	18,000	- 9,590	- 9,590	- 399	26
1,000 km in 48 hours	1 male	12,120	16,772	- 4,650	- 2,325	- 96	36
1,126 km in 48 hours	1 male	11,098	14,486	- 3,290	- 1,645	- 65	50
2,272 km in 5 d 7 h	1 male	51,246	80,800	- 29,554	- 5,585	- 232	17
4,701 km in 9 d 16 h	1 male	96,124	179,650	- 83,526	- 8,352	- 360	22
Mean (SD)					- 6,298 ± 3,392	- 258 ± 134	
Running							
160 km in 20 h	1 male	9,600	8,480	- 1,120		- 56	51
320 km in 54 h	1 male	14,760	18,120	- 3,360	- 1,493	- 62	23
501 km in 6 days	1 male	39,666	54,078	- 14,412	- 2,402	- 100	21
Atacama crossing	1 male	37,191	101,157	- 63,966	- 3,046	- 127	37
100 km	11 female	570	6,310	- 5,750		- 452	52
100 km	27 male	760	7,420	- 6,660		- 580	53
Mean (SD)					- 2,313 ± 780	- 229 ± 227	
Triathlon							
Triple Iron ultra-triathlon	1 male	15,750	27,485	- 11,735	- 6,869	- 286	54
Triple Iron ultra-triathlon	1 male	22,500	28,600	- 6, 100	- 3,404	- 141	31
Gigathlon multi-stage triathlon	1 male	38,676	59,622	20,646	- 9,937	- 414	29
10 x Ironman triathlon	1 male	77,640	89,112	- 11,480	- 7,544	- 314	55
Mean±SD					- 6,938 ± 2,699	- 288 ± 112	

in multi-sports disciplines and cycling. In running, the energy deficit is approximately three times lower than it is in both triathlon and cycling.

Change in body mass during an ultra-endurance performance

A further important fact in ultra-endurance racing is the finding that an ultra-endurance performance generally results in a loss in body mass (Table 3) [17,21-23,25,27,28,31,35-37,48,49,52,54,55-68]. The loss in body mass occurs most often in the lower trunk [21,37,60]. Depending on the length of the endurance performance and the discipline, the decrease in body mass corresponds to a decrease in fat mass [17,23,26,33,34,55,56,62-67] and/or skeletal muscle mass [17,24,32,55,56,58,59,61,62,66].

The total amount of amino acid oxidation during endurance exercise is only 1-6% of the total energy cost of exercise [69]. The decrease in skeletal muscle mass due to protein degradation is most probably very low. Concentric endurance performance, such as cycling, results in a decrease in fat mass [34,65], whereas an eccentric endurance performance, such as running, results in a decrease in muscle mass [59].

In runners, a decrease in both fat mass and skeletal muscle mass has been reported [58,59]. For swimmers, no change in body mass, fat mass or skeletal muscle mass has been reported for 12-hour indoor pool swimmers [70]. In male open-water ultra-swimmers, however, a decrease in skeletal muscle mass was observed [71].

However, also an increase in body mass can occur during an ultra-endurance performance (Table 3) [28,31,36,57,60]. Additionally, an increase in skeletal muscle mass has also been reported [28,31,34,36,54,57,60]. The increase in body mass was most probably due to fluid overload. An increase in estimated skeletal muscle mass might occur in cases where anthropometric methods were used and an increase in skin-fold thicknesses and limb circumferences was measured. Overall, ultra-endurance athletes seemed to lose approximately 0.5 kg in body mass and approximately 1.4 kg in fat mass where skeletal muscle mass seemed to remain largely unchanged. Additionally, total body water seemed to increase by approximately 1.5l [35,36,52,54-58].

Dehydration, fluid intake and fluid overload

Dehydration refers both to hypohydration (*i.e.* dehydration induced prior to exercise) and to exercise-induced dehydration (*i.e.* dehydration that develops during exercise). The latter reduces aerobic endurance performance and results in increased body temperature, heart rate, perceived exertion, and possibly increased reliance on carbohydrates as a fuel source [72]. Most endurance athletes are concerned with dehydration during an ultra-endurance performance. Generally, ultra-endurance athletes do not meet their fluid demand during exercise [5]. It has been shown that body mass was lost during a 24-hour ultra-marathon [73]. However, body mass loss in ultra-endurance athletes seems to be

Table 3. *Change in body composition in ultra-endurance athletes in different disciplines*

Distance and/or time	Subjects	Change in body mass (kg)	Change in fat mass (kg)	Change in muscle mass (kg)	Change in body water (l)	Reference
Swimming						
24-h swim	1 male	- 1.6	- 2.4	- 1.5	- 3.9	49
12-h swim	1 male	- 1.1		- 1.1		48
Cycling						
12-h indoor cycling	1 male	- 0.4	- 0.9	+ 0.2		34
617 km in 24 hours	1 male	+ 4.0	+ 0.9	+ 2.9		28
1,000 km within 48 hours	1 male	+ 2.5	- 1	+ 0.4	+ 1.8	36
2,272 km in 5 d 7 h	1 male	- 2.0	- 0.79	- 1.21		17
4,701 km in 9 d 16 h	1 male	- 5	-	-		22
Running						
12-h run	1 male	+ 1.5	- 4.4	+ 1.0	+ 4.9	57
320 km in 54 h	1 male	- 0.4	- 0.3	- 1.0		23
501 km in 6 days	1 male	- 3.0	- 6.8			21
100 km in 762 min	11 females	- 1.5			+ 2.2	52
100 km in 11:49 h:min	39 males	-1.6	- 0.4	- 0.7	+ 0.8	56
338 km in 5 days	21 males			- 0.6		59
1,200 km in 17 days	10 males		-3.9	- 2.0	+ 2.3 l	58
Triathlon						
Triple Iron ultra-triathlon in 41 h	1 male	- 1.1	- 0.4	+ 1.4	+ 2.0	54
Triple Iron ultra-triathlon in 43 h	1 male	+ 2.1	+ 0.4	+ 4.4		31
Deca Iron ultra-triathlon	1 male	+ 3.2	+ 2.4	+ 2.4		60
Quintuple Iron ultra-triathlon	1 male	- 0.3	- 1.9		+ 1.5	35
10 x Ironman triathlon in 128 h	1 male	- 1.0	- 0.8	- 0.9	+ 2.8	55
Ironman in 11 h 36 min	27 males	- 1.8		- 1.0		61
Triple Iron ultra-triathlon	31 males	- 1.7	- 0.6	- 1.0		62
10 x Ironman triathlon in128 h	8 males		- 3			63
Mean±SD		- 0.4 ± 2.5	- 1.4 ± 2.3	+ 0.1 ± 1.9	+ 1.5 ± 1.30	

due to a decrease in sold mass and not dehydration [62,64,74]. Endurance athletes should attempt to minimize dehydration and limit body mass losses due to sweating to 2-3% of body mass [7]. Adequate fluid intake prevents loss in body mass [41]. However, fluid overload may lead to an increase in body mass [75] and a decrease in plasma sodium [75] with the risk of EAH [75-77].

Recent trends towards excessive fluid intake have resulted in frequent reports of hyponatremic hyperhydration in ultra-distance athletes, with a greater incidence in women than in men [4]. Fluid overload may lead to a considerable increase in body mass [75]. For example, one athlete competing in a Deca Iron ultra-triathlon with 38km of swimming, 1,800km of cycling and 422 km of running in 12 d 20 h showed an increase in body mass of 8kg within the first three days [60]. Unfortunately, energy intake, energy expenditure and fluid intake were not recorded, but the changes in skinfold thickness showed that edemas during the race had occurred. In athletes with post-race increases in body mass, increased skin-fold thicknesses and limb circumferences of the lower limb were also recorded [36,60]. In an athlete with an increase in body mass, an increase in skin-fold thicknesses at four skin-fold sites was also reported [28]. Both of these races were held in rather hot environments where most probably fluid intake was rather high.

However, in athletes with decreases in body mass, an increase in lower limb skin-fold thicknesses has also been reported [17,55,67]. In one athlete with a decrease in body mass after a Triple Iron ultra-triathlon, a considerable swelling of the feet was reported [54]. The timing in measuring skin-fold thicknesses and limb circumferences post-race is important because body mass and total body water may increase days after the race is finished [54].

The increase in body mass, skin-fold thicknesses and limb circumferences was most probably due to an increase in total body water (Table 3) [36,55,78]. An increase in total body water has been reported in ultra-endurance athletes [35,36,52,54-58,63,79,80]. The question is why both the skin-fold thicknesses and total body water increased. The increase in total body water might be due to an increase in plasma volume [35,79-82], which in turn might be due to sodium retention [79,81] due to increased activity of aldosterone [35,83]. An association between an increase in plasma volume and an increase in the potassium-to-sodium ratio in urine might suggest that the increased activity of aldosterone [84] may result in retention in both sodium and fluid during an ultra-endurance performance [53]. In a multi-stage race over seven days, total mean plasma sodium content increased and was a major factor in the increase in plasma volume [79].

Apart from these pathophysiological aspects, fluid overload might also result in an increase in limb volume. A recent study showed a relationship between changes in limb volumes and fluid intake [85]. Since neither renal function nor fluid regulating hormones were associated with changes in limb volumes, fluid overload is the most likely reason for an increase in both body mass and limb volumes. An actual study showed an association between an increased fluid intake and swelling of the feet in ultra-marathoners [86].

Fluid intake and exercise-associated hyponatremia (EAH)

Fluid overload during an endurance performance might lead to exercise-associated hyponatremia (EAH), defined as a serum sodium concentration ($[Na^+]$) <135 mmol/l during or within 24 hours of exercise [87]. EAH was first described in the literature in 1985 by Noakes *et al.* where ultra-marathoners in South Africa with hyponatremia were thought have had 'water intoxication'[88]. Three main factors are responsible for the occurrence of EAH in endurance athletes: (*i*) overdrinking due to biological or psychological factors; (*ii*) inappropriate secretion of the antidiuretic hormone (ADH), in particular, the failure to suppress ADH-secretion in the face of an increase in total body water (TBW); and (*iii*) a failure to mobilize Na^+ from the osmotically inactive sodium stores or alternatively inappropriate osmotic inactivation of circulating Na^+ [87]. In that the mechanisms causing factors (*i*) and (*iii*) are unknown, it follows that the prevention of EAH requires that athletes be encouraged to avoid overdrinking while exercising.

EAH is the most common medical complication of ultra-distance exercise and is usually caused by excessive hypotonic fluid intake [89,90]. The main reason for developing EAH is the tendency of overdrinking during an endurance performance, by either an excessive fluid consumption [76] and/or inadequate sodium intake [91]. Subjects developing EAH during an ultra-endurance performance consumed twice as much fluid as those subjects without EAH [76]. Generally, fluid overload is reported for slower athletes [92]. However, in ultra-endurance athletes, faster athletes drink more than slower athletes but did not develop EAH [93,94].

The environmental conditions seemed to influence the prevalence of EAH. EAH was a common finding in ultra-endurance races held in extreme cold [91,95] or extreme heat [75,96]. In temperate climates, EAH was, however, relatively uncommon [83,97-110]. There seemed to be a gender difference where females seemed to be at higher risk for EAH [95]. The prevalence of EAH in ultra-marathoners [101,110,114] was, however, not higher compared to marathoners [92,111-113].

The prevalence of EAH seemed also to be dependent on the discipline (Table 4). While EAH was highly prevalent in ultra-swimming [95] and ultra-running [96], the prevalence of EAH was low [99,115] or even absent [98,100] in ultra-cyclists. In addition, the length of an ultra-endurance race seemed to increase the risk for EAH. The highest prevalence of EAH has been found in Ironman triathlons [106,108], Triple Iron ultra-triathlons [109] and ultra-marathons over 161 km [75,96].

Nutritional aspects during ultra-endurance racing

Guidelines for nutrition strategies for ultra-endurance races are absent since there has been very little research into optimal nutritional practices in extreme sporting events. The few investigations that have indeed been conducted have mainly been case studies. No controlled studies linking specific nutritional strategies with higher performances do exist. The comprehensive nutritional analyses of the intake patterns of ultra-endurance athletes who manage to avoid health difficulties, such as gastrointestinal distress and mental disorientation commonly associated with ultra-distance efforts have yet to be compared to the nutrient and fluid intakes of ultra-athletes who fall prey to these problems. Adequate energy and fluid intake is needed to successfully compete in an ultra-endurance race [116-124]. Most studies are descriptive in nature and reporting the distribution of carbohydrates, fat and protein the athletes ingested (Table 5) [17,21,22,28,29,31,116,119,120]. Some studies report on the kind of food consumed [121-123] and some studies investigated the aspect of supplements [125-128].

Intake of carbohydrates

Carbohydrates are the main source of energy intake for ultra-endurance athletes [17,38,55,118]. When the intake of carbohydrates, fat and protein during ultra-endurance racing was analyzed for ultra-endurance athletes, the highest percentage was found in carbohydrates. Ultra-endurance athletes consume approximately 68% of ingested energy as carbohydrates (Table 5).

Table 4. *Prevalence of exercise-associated hyponatremia in ultra-endurance athletes in different disciplines*

Distance and/or time	Conditions	Subjects	Prevalence of exercise-associated hyponatremia	Reference
		Swimming		
26-km open-water ultra-swim	Moderate	25 males and 11 females	8 % in males and 36% in females	95
Cycling				
665-km mountain bike race	Moderate	25 cyclists	0 %	98
109 km cycle race	Moderate	196 cyclists	0.5 %	99
720-km ultra-cycling race	Moderate	65 males	0 %	100
		Running		
161-km mountain trail run	Hot	45 runners	51 %	75
161-km mountain trail run	Hot	47 runners	30 %	96
60-km mountain run	Moderate	123 runners	4 %	101
100-km ultra-marathon	Moderate	50 male runners	0 %	83
100-km ultra-marathon	Moderate	145 male runners	4.8 %	94
24-hour ultra-run	Moderate	15 males	0 %	102
90-km ultra-marathon	Moderate	626 runners	0.3 %	88
160-km trail race	Hot	13 runners	0 %	41
		Multi-disciplines		
100-mile Iditasport ultra-marathon	Cold	8 cyclists and 8 runners	44 %	91
161-km race	Cold	20 athletes	0 %	103
Kayak, cycling and running	Moderate	48 triathletes	2 %	104
Ironman triathlon	Moderate	330 triathletes	1.8 %	105
Ironman triathlon	Moderate	330 triathletes	18 %	106
Ironman triathlon	Moderate	95 triathletes	9 %	107
Ironman triathlon	Moderate	18 triathletes	28 %	108
Triple Iron ultra-triathlon	Moderate	31 triathletes	26 %	109

Table 5. *Intake of energy in ultra-endurance athletes in different disciplines*

Distance and/or time	Subjects	Intake of carbohydrates (%)	Intake of fat (%)	Intake of protein (%)	Reference
		Cycling			
617 km in 24 hours	1 male	64.2	27	8.8	28
2,272 km in 5 d 7 h	1 male	75.4	14.6	10.0	17
4,701 km in 9 d 16 h	1 male	75.2	16.2	8.6	22
		Running			
100 km	7 males	88.6	6.7	4.7	119
501 km in 6 days	1 male	40.0	34.6	25.4	21
1,005 km in 9 days	1 male	62	27	11	122
		Triathlon			
Deca Iron ultra-triathlon	1 male	67.4	15.6	17.0	120
Gigathlon	1 male	72	14	13	29
Triple Iron ultra-triathlon	1 male	72	20	8	31
Mean (SD)		68.5 ± 13.2	19.5 ± 8.5	11.8 ± 6.1	

Intake of fat

An increased fat intake pre-race leads to an increase in intramyocellular lipids in ultra-endurance athletes [31]. Increased intramyocellular lipids might improve ultra-endurance performance. However, field studies with controlled data do not exist with regard to whether fat loading improves ultra-endurance performance. In a case report, the ultra-endurance performance of a rower was enhanced after following a high fat diet for 14 d [129]. An increased fat intake during an ultra-endurance competition might well improve performance. However, also for this conclusion, field studies with controlled data do not exist. In a case report on an ultra-marathoner competing in a six-day ultra-marathon, the athlete consumed 34.6% fat in his daily food intake [21]. Nonetheless, body fat decreased in the first two days and was unchanged until the end of the race. In addition, performance slowed down after the first two days. Ultra-endurance athletes consume approximately 19% of energy as fat, which is higher than consumed energy in the form of protein (Table 5).

Intake of protein

Regarding protein intake, athletes consume approximately 12% of ingested energy as protein during racing. An observational field study at the 'Race across America' showed that ultra-endurance cyclists ingest rather large amounts of protein [121]. One might assume that athletes experienced a loss in skeletal muscle mass and tried to prevent this loss by using amino acids. A recent study tried to investigate whether an increase in amino acids during an ultra-marathon prevents skeletal muscle damage [130]. The intake of amino acids showed no effect on parameters related to skeletal muscle damage.

Intake of ergogenic supplements, vitamins and minerals

A dietary supplement, such as vitamins and minerals, is characterized as a product which can be used to address physiological or nutritional issues in sports. It may provide a convenient or practical means of consuming special nutrient requirements for sport activity, or it may be used to prevent/reverse nutritional deficiencies that commonly occur in athletes. The basis of the dietary supplement is an understanding of nutritional requirements and physiological effects of exercise. When the supplement is used to meet a physiological/nutritional goal triggered by sport activity, it may be proven to enhance sports performance [131]. Vitamin and mineral supplements are frequently used by competitive and recreational ultra-endurance athletes during training [122,123,126,127] and competitions [120-123].

The intake of ergogenic supplements, vitamins and minerals in ultra-endurance athletes and its effect on performance has been investigated in a number of studies [125,126,128]. In long-distance triathletes, over 60% of the athletes reported using vitamin supplements, of which vitamin C (97.5%), vitamin E (78.3%), and multivitamins (52.2%) were the most commonly used supplements during training. Almost half (47.8%) the athletes who used supplements did so to prevent or reduce cold symptoms [128]. The regular intake of vitamins and minerals seems, however, not to enhance ultra-endurance performance [125,126]. In the 'Deutschlandlauf 2006' of over 1,200 km in 17 consecutive stages, athletes with a regular intake of vitamin and mineral supplements during the four weeks before the race finished the competition no faster than athletes without vitamins and minerals [125]. In a Triple Iron ultra-triathlon, athletes with a regular intake of vitamin and mineral supplements prior to the race were not faster [126]. Caffeine can be used as an ergogenic aid to help competitors stay awake during prolonged periods, enhance glycogen resynthesis and endurance performance [8].

Fluid intake during endurance performance

Ad libitum fluid intake seemed to be the best strategy to prevent EAH and to maintain plasma sodium concentration [52,83,94,132-135]. Low fluid intake between 300 ml/h and 400 ml/h seemed to prevent EAH [52,106,132]. In a 4 h march a mean *ad libitum* fluid intake of approximately 400 ml/h maintained serum sodium concentration [132]. A fluid consumption of approximately 400 ml/h prevented from EAH in a 161-km race in the cold [103].

Sodium supplementation during endurance performance

One might argue that a supplement of sodium during an endurance race might prevent EAH. However, two studies on Ironman triathletes showed that *ad libitum* sodium supplementation was indeed not necessary to preserve serum sodium concentrations in athletes competing for about 12 hours in an Ironman [136,137].

Conclusions and implications for future research

Regarding these findings ultra-endurance athletes face a decrease in body mass most probably due to a decrease in both fat mass and skeletal muscle mass. During a race, athletes are not able to compensate for their energy deficit. Athletes tend to increase their fluid intake with increasing length of an ultra-endurance performance, which seems to result in both an increased risk of EAH and limb swelling. In summary, an energy deficit seems to be unavoidable in ultra-endurance performances. The best strategy to prevent both EAH and limb swelling is to minimize fluid intake to approximately 300-400 ml per hour.

Declaration of interest

The authors report no conflicts of interest.

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